California Air Resources Board
Emissions Inventory Series

Volume 1, Issue 10

HEAVY-DUTY DIESELS

COMPRESSION IGNITION ENGINE EMISSIONS AND TESTING

Diesel-powered vehicles constitute only 3% of California's on-road vehicle population and contribute only 5% of the daily vehicle miles of travel (VMT), yet 35% of the NOx and 56% of the vehicle exhaust particulate matter were attributable to these vehicle in 2000.

The diesel fraction of the California fleet increases as a function of gross vehicle weight, ranging from 1% for passenger cars and light-duty trucks, to 10% of medium-duty vehicles and 56% of heavy-duty trucks.

As with light-duty gasoline powered vehicles, the emissions inventory for heavy-duty diesel vehicles is calculated as the product of an emission rate, vehicle population and a measure of activity. Historically, the emission rates are derived from test of engines, rather than complete vehicles, and is expressed in terms of mass per unit of work or grams per brake-horsepower-hour (g/bhp-hr). To derive an inventory, a correction factor must be used to convert the g/bhp-hr emissions estimates to grams per mile.

This conversion was performed using a single factor which was essentially a measure of vehicular and engine efficiency.

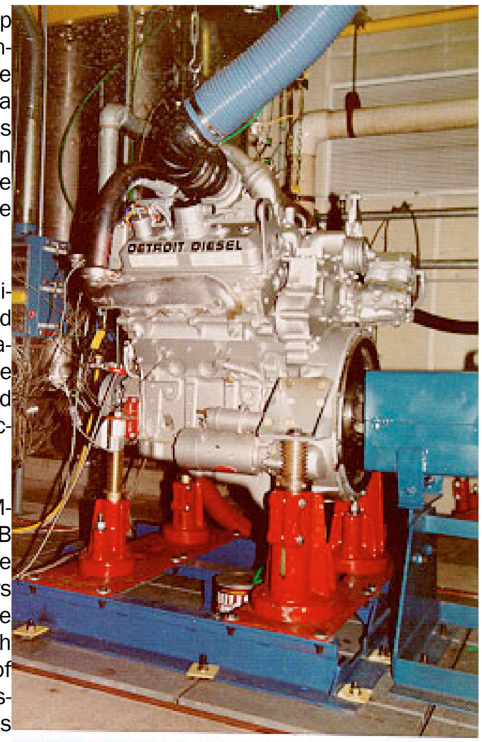
Conversion Factor =

Fuel Density / BSFC*MPG

Where Fuel Density is expressed as pounds per gallon of fuel, BSFC is the brake specific fuel consumption and MPG is the fuel economy of the vehicle expressed as miles per gallon.

EMFAC 2001 UDDS
Heavy-Duty Diesel Database

Year	LHDT	MHDT	HHDT	Total
1966			1	1
1981			1	1
1982	1		1	2
1983			1	1
1984	1		1	2
1985	2	1	2	5
1986	1			1
1987	2	2		4
1988	1	1	2	4
1989	1	3	1	5
1990		3	1	4
1991	1		1	2
1992	1	2		3
1993	1	4	2	7
1994	4	2	1	7
1995	2	2	2	6
1996	2	4	1	7
1997		1	1	2
1998		1	6	5
1999		1		1
2000			3	
Total	20	27	28	75



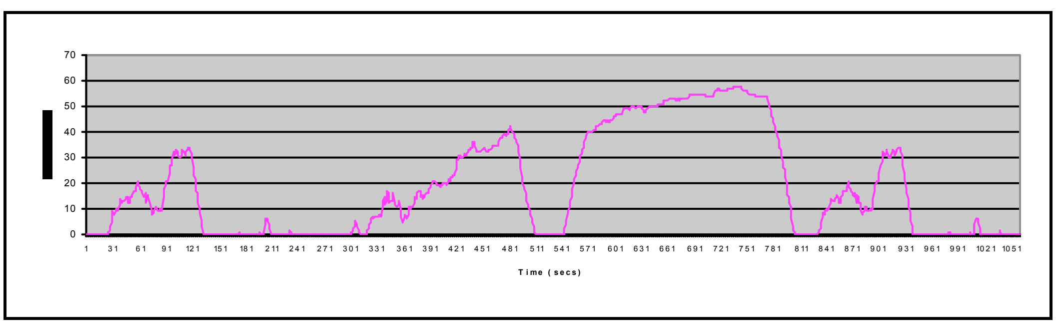
In order to develop more accurate conversion factors, one would ideally test a vehicle on a chassis dynamometer then remove the engine for test on an engine stand.

However, If the vehicle could be tested on a chassis dynamometer, there would be no need for a conversion factor.

Beginning with EMFAC 2000, ARB abandoned the use of conversion factors and the 30 engine database which formed the basis of the heavy-duty emission inventory. In its place, chassis dynamometer data collected for 70 trucks tested over the Urban Dynamometer Driving Schedule (UDDS) were used.

Although the use of UDDS-generated test data marked a significant improvement in the inventory, few believed that the UDDS adequately represented the full range of heavy-duty diesel operation. Although the cycle was constructed from actual truck activity data, it lacks extended cruises known to cause many trucks to default to a high NOx emitting, fuel saving mode referred to as **"Off-Cycle" NOx.** The cycle also lacks hard accelerations known to result in high emissions of particulate matter.

THE URBAN DYNAMOMETER DRIVING SCHEDULE



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HEAVY-DUTY DIESELS

It is assumed that the emissions of heavy-duty diesels will not deteriorate in the absence of acts of tampering and mal-maintenance. This assumption is based on analyses of chassis dynamometer tests performed on over 80 diesel powered transit buses by the New York Department of Environmental Protection. Chassis dynamometer data has been used in the on-road inventory since EMFAC7G.

Deterioration in the heavy-duty diesel fleet is modeled as the product of the frequency of occurrence and the effect on emissions of 19 separate instances of tampering and mal-maintenance. Lacking a periodic inspection program for these vehicles, limited information is available to estimate the occurrence of these problems and quantifying their affects requires comparing baseline tests of vehicles with defects to their emissions after repair.

Two such programs were performed by the Radian Corporation in 1987 and the Colorado Institute for Fuels and Engine Research in 1998. The results show that 10-fold increases in emissions associated with acts of tampering and mal-maintenance are not uncommon in the heavy-duty diesel fleet.

The "Radian" model is used outside of the on-road inventory to estimate the effects of tampering and mal-maintenance. The output of the model is essentially an estimate of the percent increase in overall fleet emissions as a result of these acts. These estimates are incorporated into EMFAC as deterioration rates or increase in emissions expressed as grams per mile increase per 10,000 miles driven.

ACTIVITY

Activity data for heavy duty diesels are derived from instrumentation of trucks, such as the studies performed for the ARB by Battelle and Jack Faucett Associates, or from surveys such as the Truck Inventory Use Survey (TIUS) performed by the Bureau of Census.

Data from the instrumented truck studies mentioned above are also being analyzed to derive more representative driving cycles for emissions inventory purposes.

The second by second speed data collected in the two instrumented truck studies have been used so far to develop a four mode heavy-heavy-duty diesel cycle. The four modes, idle, creep, transient and cruise, depict the widely varying operations of these vehicles. In general, the creep mode produces the greatest gram per mile results followed by the transient and the cruise mode. The transient and cruise modes produce higher and lower emissions, respectively, than the UDDS. The instrumented truck data also suggest that these vehicles may spend up to 42% of their operating time at idle. This idle data is being used to update the current inventory .

TAMPERING AND MAL-MAINTENANCE

The "Radian" Model is used to estimate the deterioration in heavy-duty diesel emission rates as a function of 19 separate acts of tampering and mal-maintenance. The model was designed to assess the benefits of subjecting heavy-duty trucks to periodic inspection akin to the "Smog Check" program for light duty vehicles.

1. Timing Advanced
2. Timing Retarded
3. Minor Injector Problem
4. Moderate Injector Problem
5. Severe Injector Problem
6. Puff Limiter Misset
7. Puff Limiter Disabled
8. Maximum Fuel High
9. Clogged Air Filter
10. Wrong/Worn Turbo
11. Intercooler Clogged
12. Other Air Problem
13. Engine Mechanical Failure
14. Excess Oil Consumption
15. Electronics Failed
16. Electronics Tampered
17. Catalyst/Trap Removed
18. EGR Stuck Open
19. EGR Disabled

ARB'S FOUR MODE CYCLE